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# Emission sparks around M 81 and in some dSph galaxies ⋆ †

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**ABSTRACT**

We use $H\alpha$ images of three clumps of young stars situated between M 81 and NGC 3077 to estimate their star formation rate. Radial velocities of the clumps measured by us, as well as the velocity of HII-region in the dSph galaxy KDG 61 are compatible with their location at the outskirts of a large rotating gaseous disc around M 81. In contrast to KDG 61, radial velocity of the emission knot in the dSph galaxy DDO 44, $+213 \pm 25$ km s$^{-1}$, tells us that this $H\alpha$ spark belongs to the dSph galaxy itself. F475W and F814W images of DDO 44 extracted from the HST archive reveal 8 bluish ($B - I < 0.8$) stars apparently associated with the $H\alpha$ knot.

**Key words:** galaxies: dwarf – galaxies: formation – galaxies: evolution – galaxies: stellar content – galaxies: individual: DDO 44

## 1 INTRODUCTION

Systematic $H\alpha$ line observations of the nearby ($D < 10$ Mpc) galaxies have been recently conducted at the 6-m telescope of the Special Astrophysical Observatory, Russian Academy of Sciences (SAO RAS) in order to determine the rate of star formation in them (Karachentsev et al. 2005; Kaisin & Karachentsev 2006, 2008; Kaisin et al. 2007; Karachentsev & Kaisin 2007, 2010). Unlike other similar programs (Hunter et al. 1993; Bell & Kennicutt 2001; James et al. 2004; Hunter & Elmegreen 2004; Kennicutt et al. 2008), we did not restrict our program to any selected morphological types of galaxies. With almost the same enthusiasm we observe both the gas-rich spiral, irregular and blue compact galaxies, as well as the "dead" elliptical, lenticular and dwarf spheroidal galaxies, where the current rates of star formation are assumed to be close to zero. Such non-selective approach to the compilation of target list has led to detection of a circumnuclear $H\alpha$ emission from a number of isolated E, S0 galaxies (Moiseev et al. 2010), indicating the ongoing quasi-stationary process of accretion of the intergalactic gas onto the central parts of galaxies.

Another unexpected result of our survey was the discovery in some dSph galaxies of small emission clumps, which we designated as "sparks". As it is known, the neighboring group around the giant spiral M 81 is rather rich in dwarf spheroidal systems. Some of them: BK5N, BK6N, FM1, IKN, KKH 70 do not show any signs of emission in the $H\alpha$ line, and the optical bodies of others (DDO 44, DDO 78, F8D1, KDG 63) reveal fine structural details after the subtraction of continuum **(Karachentsev & Kaisin 2007)** . Such details may be the result of an incomplete subtraction of the continuum of very red stars, or an artifact from cosmic rays. It seems unlikely that the old, "bald", devoid of neutral hydrogen spheroidal dwarfs contain small sites of star formation. To verify the nature of the hypothesized emission clumps in dSph galaxies, we carried out spectral observations, the results of which are given in this article.

## 2 EMISSION SPARKS AROUND M 81

As shown by Appleton et al. (1981); Yun (1999); Boyce et al. (2001), the region of the M 81 group is filled with filament structures of neutral hydrogen, which connect M 81 with the neighboring bright galaxies M 82, NGC 3077 and NGC 2976. It is assumed that this complex HI pattern was formed as a result of tidal interaction of the brightest group members. In the most dense parts of the HI filaments, the process of star formation is already underway. It led to the formation of tidal dwarfs: Garland, Holmberg IX, Arp loop (A0958+66) and BK3N (Makarova et al. 2002), where the old ($T > 2$ Gyr) stellar population is absent. Brinks et al. (2008) and Chynoweth et al. (2011) have found in the M 81 group a significant number of small HI-clouds with masses of $\sim 10^5 - 10^6 M_\odot$, free-floating between bright galaxies. Some of them coincide in position with the dSph dwarf galaxies, for example, KKH 57.

⋆ Based on observations made with the 6m BTA telescope of the Special Astrophysical Observatory, Russian Academy of Sciences.
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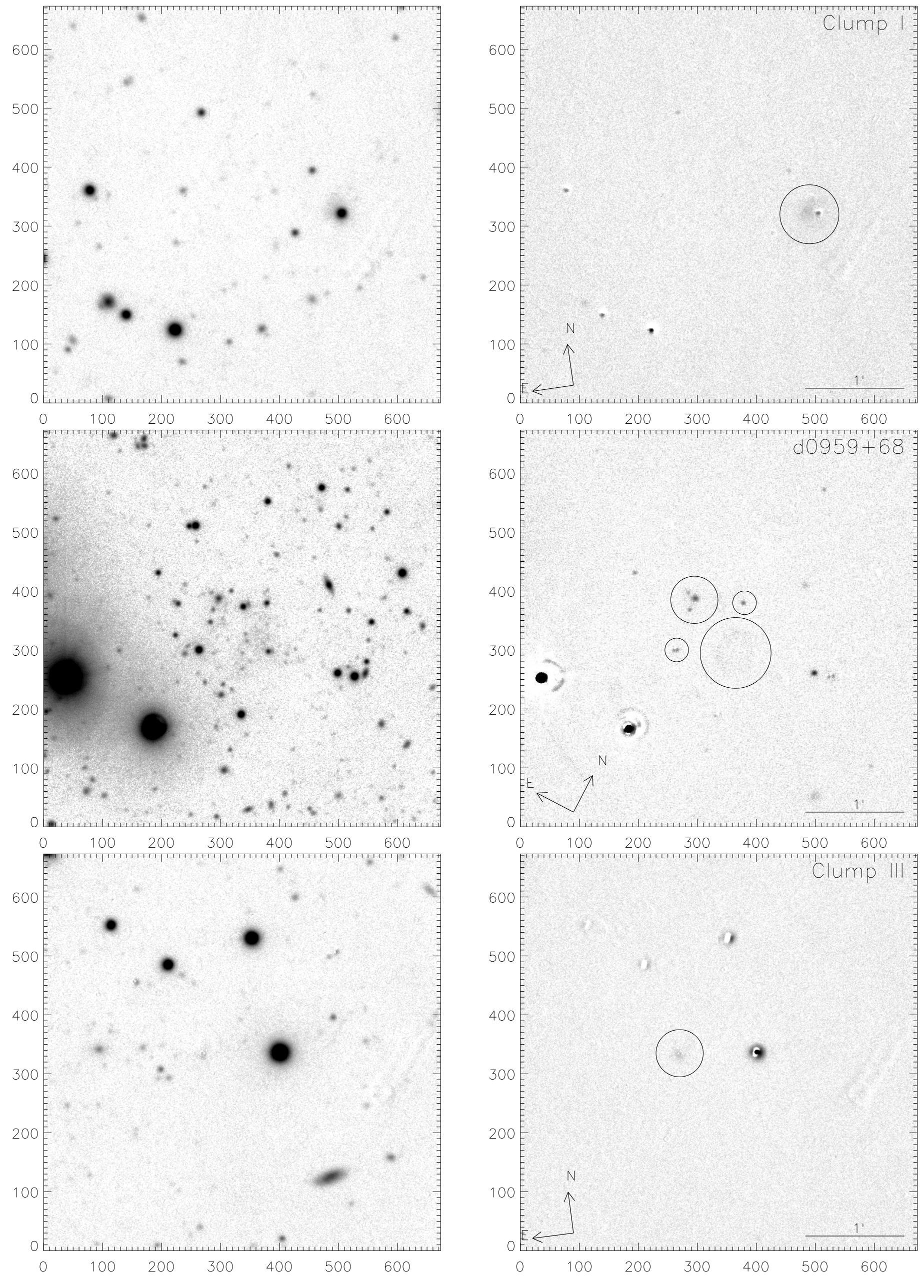


**Figure 1.** $H\alpha$ (left) and continuum-subtracted (right) images of three emission clumps between M 81 and NGC 3077. North and east are indicated by arrows.

Mouhcine & Ibata (2010) obtained deep images with MegaCam at the CFHT in the "g" and "i" filters of an area sized $\sim 1$ square degree between M 81 and NGC 3077 at subarcsecond seeing. On these images the authors found three knots: clump I, clump II, and clump III, resolved into blue stars. All of them are located approximately along the HI arm, connecting M 81 and NGC 3077. These bluish clumps are similar to other blue star complexes, detected earlier in the closer periphery of M 81 (Durrell et al. 2004; de Mello et al. 2008; Davidge 2008). Note that similar groups of young (blue) stars were recently detected with the ultraviolet GALEX satellite on the periphery of other nearby galaxies: NGC 404 (Thilker et al. 2010), NGC 628, NGC 2841, NGC 3621 and NGC 5055.

Figure 1 shows the images of the Clump I, II and III, obtained with the 6-m BTA telescope of the SAO RAS. The images in the $H\alpha$ line and in the continuum were made in November 2010 with the SCORPIO focal reducer (Afanasiev & Moiseev 2005). A $2048 \times 2048$ pixel CCD chip provided the field of view of 6' with the resolution of 0.18" per pixel. To obtain the images in $H\alpha$ we used an interference filter 75Åwide at the effective wavelength of 6555Å, while to subtract the continuum pairs of images with the filters SED607 ($\lambda_{ef}$ = 6063Å, $\Delta\lambda$ = 167Å) and SED707 ($\lambda_{ef}$ = 7063Å, $\Delta\lambda$ = 207Å) were taken. The exposure time amounted to $2 \times 600$s in $H\alpha$ and $2 \times 300$s in the continuum. To calibrate the $H\alpha$ fluxes, we also observed the spectrophotometric standards by Oke (1990). The left-hand side images in

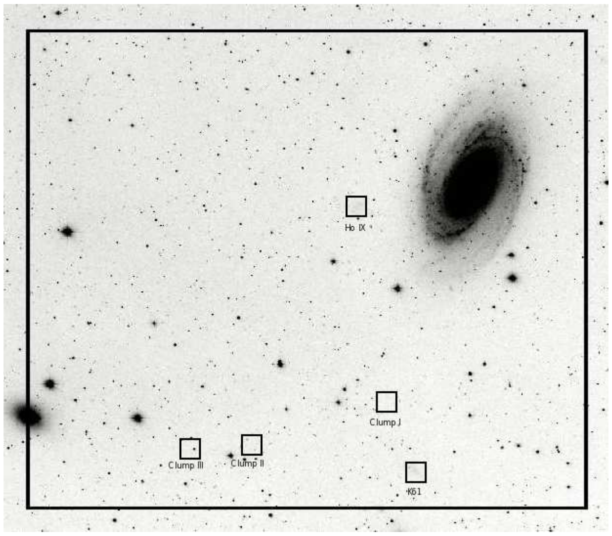


**Figure 2.** One square degree view of the south-east outskirts of M 81 from Mouhcine & Ibata (2010). Three emission clumps and dSph galaxy KDG 61 are indicated by squares.

Fig. 1 correspond to the total image $H\alpha$ + continuum, and the right-hand images show the difference $H\alpha$ –continuum. To determine the $H\alpha$ flux we used a standard sequence of procedures we previously described (Karachentsev & Kaisin 2010).

All the three objects exhibit a weak $H\alpha$ emission, most pronounced in the case of the object Clump II = d0959+68 (Chiboucas et al. 2009), where several compact HII-regions, as well as a low-contrast diffuse emission zone are visible. The measured integral $H\alpha$ fluxes of these objects are presented in Table 1. We as well added there the $H\alpha$ fluxes of the emission clumps in two other dwarf members of the group: DDO 44 and KDG 61, we previously measured (Karachentsev & Kaisin 2007). The table also lists apparent and absolute magnitudes of the objects and their integral star formation rate $SFR(M_\odot \cdot yr^{-1}) = 1.27 \cdot 10^9 \cdot F_c(H\alpha) \cdot D^2$ according to Gallagher et al. (1984), where $F_c(H\alpha)$ is the flux corrected for Galactic absorption, and $D$ is the distance in Mpc.

We used the detected emission clumps to determine their radial velocities. Spectral observations were performed in the primary focus of the 6-m telescope with the SCORPIO focal reducer operating in the long slit mode. The spectra of 6 objects were obtained in the red region with FWHM =5Å and the resolution of 0.86Å per pixel. The heliocentric velocities $V_h$ of the observed objects, measured from the $H\alpha$ line are presented in Table 2, with indications of velocity measurement errors. The following columns of Table 2 list: radial velocity of the object relative to the centroid of the Local Group, linear projected distance from M 81 (or from NGC 2403 in the case DDO 44), as well as the position angle of the dwarf object relative to the major axis of the main galaxy (M 81 or NGC 2403). The last two rows of the table contain our new estimates of radial velocities for the dwarf galaxy d1019+69 from the list by Chiboucas et al. (2009), as well as UGC 8245, earlier observed by Falco et al. (1999). The galaxy UGC 8245 is a possible peripheral member of the M 81 group.

Figure 2 reproduces the location of the observed objects relative to the M 81. The rectangular frame indicates the area of the image sized $58' \times 56'$, obtained by Mouhcine & Ibata (2010). The galaxy NGC 3077 with the adjacent tidal dwarf structure Garland is located on the left edge of this field. Near the lower edge of Fig. 2 a dwarf spheroidal galaxy KDG 61 is present. On its NE side a bright HII region is visible, for which Johnson et al. (1997) have measured the radial velocity $V_h = -135 \pm 30$ km s$^{-1}$. Later, similar values of radial velocity for this emission spot: $V_h = -116 \pm 21$ km s$^{-1}$ and $-123 \pm 6$ km s$^{-1}$ were obtained by Sharina et al. (2001) and Makarova et al. (2010). Since Makarova et al. (2010) measured the radial velocity of $+222 \pm 3$ km s$^{-1}$ for the central globular cluster in KDG 61, they assumed that the bright HII region is not associated with the galaxy KDG 61 itself, but that it is rather projected onto it from the far periphery of the M 81. In other words, the dSph galaxy behaves as a screen, on which the projected structures are easily distinguishable.

**Table 2.** New radial velocities in the M 81 group

| Object | $V_h$ km/s | $V_{LG}$ km/s | $R_p$ kpc | $\Delta PA$ deg | Note |
|---|---|---|---|---|---|
| Clump I | $-165 \pm 18$ | $-25$ | 23 | 7 | |
| d0959+68 | $-186 \pm 44$ | $-46$ | 35 | $-12$ | Clump II |
| Clump III | $-121 \pm 20$ | 19 | 39 | $-19$ | |
| **KDG 61** | $-123 \pm 06$ | 17 | 30 | 16 | $V_h$ from[b] |
| DDO 44 | $+213 \pm 25$ | 356 | 74 | 42 | |
| d1019+69 | $+557 \pm 38$ | 697 | – | – | backgr. dIr |
| UGC 8245 | $-58 \pm 55$ | 145 | – | – | $V_h = 70 \pm 59$[a] |

[a] Falco et al. (1999)
[b] Makarova et al. (2010)

The field of HI radial velocities for the galaxy M 81, built by Rots & Shane (1974) up to the angular distances of $\sim 30'$ from the center shows that at the southern periphery of the M81 the position angle sector of $\pm 20°$ relative to the major axis of M 81 is dominated by the radial velocities $V_h \simeq [-140 \pm 30]$ km s$^{-1}$. As seen from Table 2, the velocities of Clumps I, II, III, and emission knot in KDG 61 lie exactly within the specified range. Consequently, all these emission objects can be considered as the elements of the far periphery of the M 81 gas disk, which has a nonuniform filamentary structure with small sites of star formation.

## 3 THE EMISSION CLUMP IN DDO 44

A dwarf spheroidal galaxy DDO 44 is located at 79 arcmin in the direction of NNW from the Sc galaxy NGC 2403. The distance to it, based on the tip of the red giant branch was measured by Karachentsev et al. (1999); Alonso-García et al. (2006); Dalcanton et al. (2009). The mean distance value amounts to $3.20 \pm 0.10$ Mpc, which almost coincides with the distance estimate of $3.13 \pm 0.10$ Mpc to NGC2403 from the Cepheids (Freedman et al. 2001). The emission knot we discovered in DDO44 with the coordinates 073419.1 +665323.5 (J2000.0) is located in the NE side of the galaxy within its optical boundaries.

On the negative image of DDO 44, extracted from the SDSS, the $H\alpha$ spark is marked by a square (Fig. 3). The heliocentric radial velocity of the emission spot in DDO 44

**Table 1.** H-alpha flux and SFR for the emission sparks

| Object | RA (2000.0) | Dec | $B_T$ | $M_B$ | logF(H$\alpha$) | log[SFR] |
|---|---|---|---|---|---|---|
| Clump I | 09 57 21.2 | +68 42 55 | 19.8 | − 7.6 | −15.04 | −4.82 |
| d0959+68 | 09 59 33.1 | +68 39 25 | 18.0 | −10.2 | −13.99 | −3.77 |
| Clump III | 10 00 40.4 | +68 39 37 | 19.8 | − 7.5 | −14.34 | −4.12 |
| KDG 61 | 09 57 02.7 | +68 35 30 | 15.2 | −12.9 | −13.36 | −3.08 |
| DDO 44 | 07 34 11.3 | +66 53 10 | 15.6 | −12.1 | −15.22 | −5.07 |

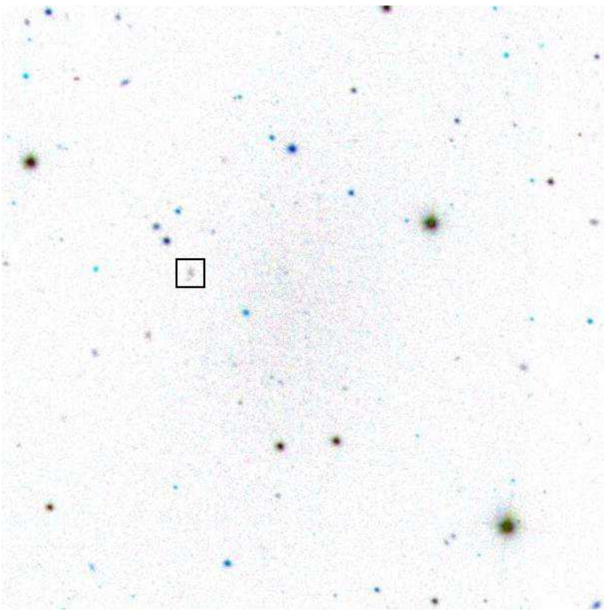

**Figure 3.** SDSS image of DDO 44. The emission spark is indicated by square.

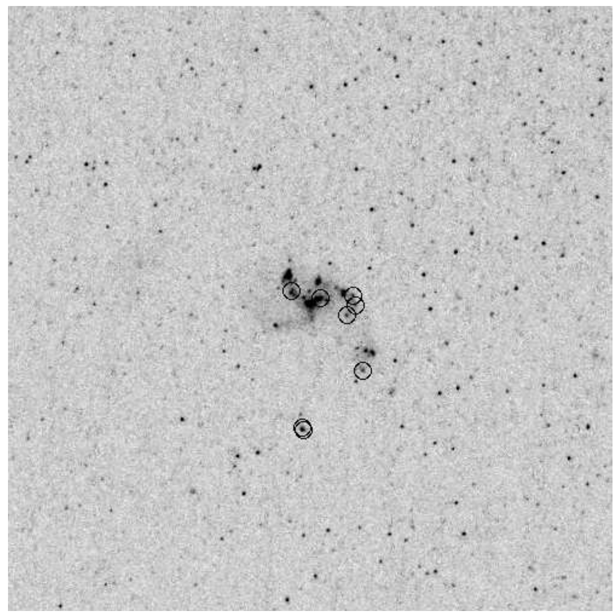

**Figure 4.** F475W-band image of the HII-region in DDO 44. The image size is 25 arcsec (388 pc). Eight bluish ($B-I<0.8$) stars are marked by circles.

(+213 ± 25) km s$^{-1}$ differs from the mean velocity of NGC 2403 (+133±3) km s$^{-1}$ by 80 km s$^{-1}$, which is typical for dwarf satellites of spiral galaxies.

The field of radial velocities in NGC 2403 was constructed by Begeman (1987) based on observations in the neutral hydrogen 21 cm line. The resulting map of the velocity field extends to the distance of $\sim$ 18 arcmin from the center of NGC 2403, i.e. about a quarter of its distance to DDO 44. From these data, the radial velocities in the gas disk of NGC 2403 in the direction towards DDO 44 show a systematic decrease from the value of +133 to +60 km $^{-1}$. Therefore, the radial velocity of the clump in DDO 44 that we measured in no way fits into the kinematics of the peripheral gas disk of NGC 2403, and can obviously be attributed to the dSph system itself.

From the HST data archive we have picked out ACS images of DDO 44, taken with the F814W and F475W filters for the GO10915 program (PI: J. Dalcanton), and performed the DOLPHOT (Dolphin 2002) photometry of stellar populations in this galaxy. A fragment of the blue (F475W) image, sized 25"×25", with the focus on the emission object is shown in Figure 4. Emission area with the diameter of $\sim$ 4" has a rather complex spiral-like structure, due to which this HII region can easily be confused with a distant Sc galaxy. **The results of our photometry show that some of bluish objects with color indices of $B-I<0.8$ classified as stars based on the DOLPHOT quality parameters are definitely associated with the emission object.**

Eight of the bluish stars, closest to the center of the $H\alpha$ knot are marked by circles in Figure 4. The median of the apparent magnitudes for these 8 stars equals $B = 26.7^m$, while their median color index is $B-I = 0.60$. At the distance module of $27.5^m$ the median absolute magnitude of these stars corresponds to $M_B \simeq -1.2$. **It is likely that they are late-type B-stars with $M_\star > 3M_\odot$, and their total far UV-luminosity, $\sim 1\,10^{36} erg^{-1}$ is sufficient to ensure the ionization of the HII region.**

**Note that the emission spark in DDO 44 has been also detected with the GALEX as a knot of $m_{FUV} = 22.52 \pm 0.20$ and $m_{NUV} = 21.40 \pm 0.14$. Using the relation $\log \boldsymbol{SFR}[M_\odot\,\mathbf{yr}^{-1}] = 2\log D[\mathbf{Mpc}] - 0.4\,m_{FUV} + 2.78$ from Kennicutt (1998), we obtain for the spark $\log \boldsymbol{SFR} = -5.21$ in excellent agreement with the quantity $-5.07$ derived by us from the $H\alpha$ flux.**

## 4 DISCUSSION

As follows from the above data, the emission "sparks" found in the body of some nearby dwarf spheroidal galaxies have

a dual nature. They can be either compact HII-regions, projected onto the dSph galaxy from far periphery of neighboring spiral galaxies (the case of KDG 61), or small sites of star formation in dSph galaxies themselves (the case of DDO 44). The rate of star formation in these $H\alpha$ knots are characterized by the values SFR$\sim (10^{-5}-10^{-3})M_{\odot}$/yr with the integral luminosity of $L_B \sim (1-2)\cdot 10^5 L_{\odot}$, and the linear size of $\sim 50$ pc.

Another compact emission object was discovered by us in an isolated dSph galaxy KKR 25 (Kaisin & Karachentsev 2008). Spectral properties of this object are currently under study by Makarov et al. (in preparation).

An obvious question arises: do such small emission regions exist in closer dSph galaxies of the Local Group? It is yet difficult to answer this question, since there were no systematic $H\alpha$ surveys of spheroidal satellites of our Galaxy conducted because of their large angular extent.

However, in the $H\alpha$ survey of Andromeda's satellites Kaisin & Karachentsev (2006) noted the possible presence of faint emission objects on the periphery of NGC 147, And III and And X, stressing the need to verify their nature by spectral observations. It should be remembered here that the group M 81/NGC 2403 differs from the Local Group by the presence of large masses of intergalactic neutral hydrogen.

According to the HI observations by Huchtmeier et al. (2000), the dwarf spheroidal galaxy DDO 44 does not reveal any HI flux at the level of 6 mJy. Assuming the range of internal motions of $W \leqslant 30$ km s$^{-1}$, we obtain for DDO 44 the upper limit of the flux, corresponding to the hydrogen mass of $\sim 4\cdot 10^5 M_{\odot}$. It seems surprising how such a gas-poor dwarf system could form a new site of star formation.

It is possible that the existence of small single $H\alpha$ clumps in dSph galaxies is not due to internal causes, but rather to the accretion of intergalactic gas. The accretion process can have a universal character, but for all that be only notable in the "dead" systems with old population.

Further $H\alpha$ observations of dSph galaxies in other groups, as well as the use of ultraviolet survey data obtained by the GALEX satellite can be of great help in studying the phenomenon of small-scale sites of star formation in these galaxies.

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